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U. S. Department of Agriculture.

Circular No. 18.

UNITED STATES DEPARTMENT OF AGRICULTURE,

DIVISION OF FORESTRY.

PROGRESS IN TIMBER PHYSICS.

INFLUENCE OF SIZE ON TEST RESULTS; DISTRIBUTION OF MOISTURE.

The timber investigations of the Division of Forestry during the year 1897 have been confined to such inquiries as would make the test data hitherto accumulated more valuable and place the methods of testing in the future upon a more reliable and at the same time more economical basis. The one direction of the test work, that which has in view immediately practical objects, namely, to supply standards of strength values for our American timbers, has been entirely abandoned until special appropriations for the continuance of this most needful work may be made available. The other direction, namely, that which has for its aim to increase our general knowledge of the properties and behavior of wood, to furnish data for rational inspection and to elucidate principles and methods of correct use of the material, has been continued as opportunity was afforded.

VARIOUS TEST SERIES AND PRINCIPAL RESULTS.

One of the questions which has disturbed the mind of men engaged in practical construction work has been whether and how far data obtained on small laboratory pieces are applicable to construction members of the size used in practice.

To determine how far size influences test results two independent series were instituted, one with beams and columns of commercial size, from which afterwards smaller sizes were cut and tested; the other on small laboratory sizes only, in which it was attempted to find the size which furnishes most satisfactory results and also to determine what may be reasonably considered a real *difference* in strength not chargeable to the error of workmanship or machine but to inherent lack of homogeneity of material; and therefore a difference of practical significance.

Since former demonstrations have shown that the influence of moisture on strength is considerable, and since in beam tests not only the amount but the distribution of moisture must be of great moment, a series of tests in moisture distribution was also instituted. At the same time it was ascertained how far the form and size of the test piece used in determining the moisture per cent, influence the result. A further series involving 306 specimens, to determine the rate of drying under varying conditions, threw additional light on the question of moisture distribution and the behavior of water in wood.

The series of experiments on large beams and columns has been performed in the laboratory of the Washington University, at St. Louis, Mo., under supervision of Prof. J. B. Johnson, and according to his own plans, revised and approved by this office. The other series have been carried on by Mr. S. T. Neely, C. E., who is also responsible for the necessary computations and compilations of results, Mr. E. H. Stück assisting.

The tests performed at Washington, D. C., were made on a 200,000-pound Ohlsen machine with automatic weighing device and four speeds, in the laboratory of the Southern Railway Company, rented for the purpose. Unfortunately, the work was suddenly terminated by a fire which destroyed machine, building, and material, with, however, only a small loss of records, those saved furnishing acceptable results of the series here under consideration. The results of these test series have proved of the utmost practical value, clearing up many points of doubt and unquestionably advancing both the art of testing and the art of using wood.

The most important conclusions may be stated briefly at the outset, as follows:

1. *A difference in strength values derived from a few specimens of the same kind of wood, up to 10 per cent for coniferous wood and to 15 per cent for hard woods, can not be considered a difference of practical importance; such differences can not be relied upon as furnishing a criterion of the quality of the material.*

2. *The size of the test piece does not in itself influence strength values (except in compression endwise when the size is less than a cube).*

3. *Small test pieces judiciously selected furnish a better statement of average values of a species than tests on large beams and columns in small numbers.*

4. *A large series of tests on small pieces will give practically the same result as such a series on large beams and columns; hence, there is no need of finding a coefficient, with which to relate the results of the former to construction members.*

5. *The influence of moisture on strength appears even greater than the former tests and statements from this Division have indicated.*

The most important discovery of all, worked out by Mr. S. T. Neely, may be stated as follows:

1. The strength of beams at elastic limit is equal to the strength of the material in compression, and the strength of beams at rupture can, it appears, be directly calculated from the compression strength; the relation of compression strength to the breaking load of a beam is capable of mathematical expression.

MAXIMUM UNIFORMITY OF WOOD.

Wood, as is well known, is a nonhomogeneous material, and hence extremely variable in its strength and other properties; so much so that it has often been doubted whether any test series could produce reliable standard values.

We believe that it is entirely practicable to procure such standard values, provided that a large series of tests underlies these values, and at the same time data of inspection are furnished which permit the rational application of the standard value in the individual case.

One of the first requirements, it would appear, is to be clear as to the range of variation to which the wood is liable. This, as far as we know, has never been made a subject of experimental inquiry. As a consequence, discussions, needless controversies, and false conclusions on the relative value of various wood materials or processes of treatment, etc., have been frequent, having been based on differences of test data, which might have been within the range of variability of each material by itself, the difference being too small to predicate quality of the material in general. Small differences, such as a few hundred pounds in values of 10,000 pounds or more, have been regarded as deciding for or against a whole series of material or of a species, or have been utilized to establish a superiority of various processes of treatment or methods of testing or computation.

The following series was therefore designed to find what may be considered a valid difference in strength, one of practical meaning, to be considered as expressive of intrinsic difference in quality; to find, in other words, "What is the maximum uniformity of wood?" The results of the series, unfortunately cut short by the burning of the test laboratory, will suffice at least to indicate how much uniformity may be expected and to render probable that differences of less than 10 per cent in ordinary wood testing with material of conifers can not be accepted as speaking for or against any given material, and that in hard woods, especially the oaks, differences of even 15 per cent may be expected in material of the same kind, grade, and value.

SIZE OF TEST PIECE.

As a preliminary to the tests on what constitutes a valid difference, it appeared desirable to settle definitely the question as to the size of test piece that should preferably be used in such inquiry. A series of 186 compression endwise tests was made on well-selected, quarter-sawed material of Longleaf Pine and White Ash, all thoroughly seasoned. Seven scantlings, four of Longleaf Pine and three of Ash, 3 by 3 in cross section, which was reduced by planing to 2¾ inches, were cut into test pieces *seriatim*, varying in height from one-half inch to 6 inches, as shown in diagram in Table I. It was found that a marked increase of strength is noticeable only when the test piece is shorter than wide—i. e., any size shorter than a cube; and this increase continues with decrease in height down to the lowest size employed (½-inch, with the cross section of 2¾-inch).

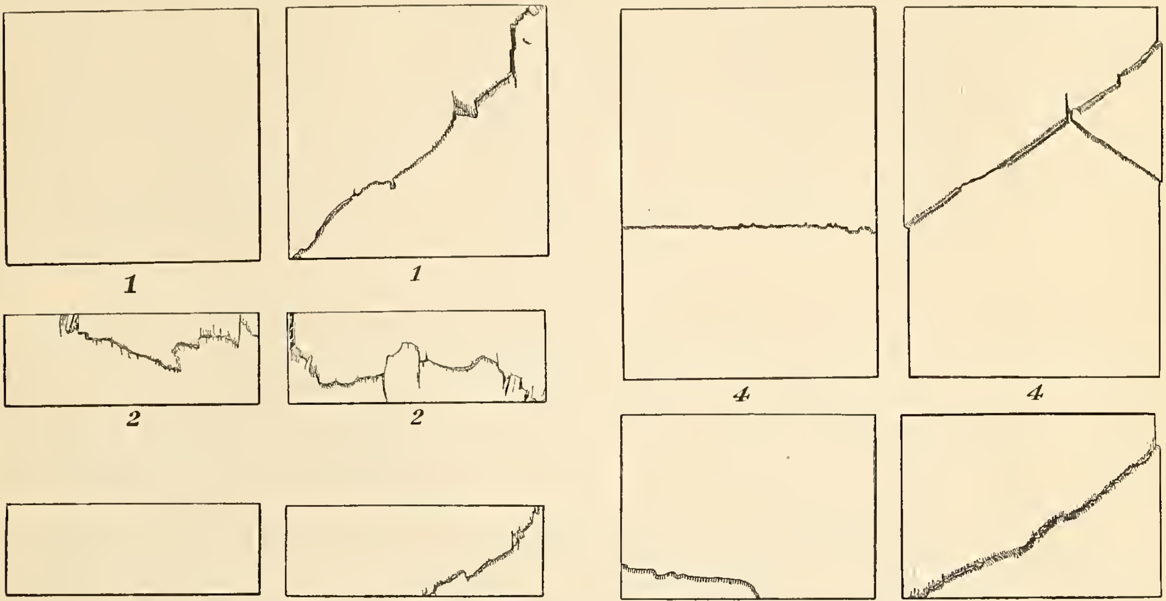


Diagram 1.—Figs. 1 to 5. Types of failure in quartersawed compression blocks.
[Lefthand figure of each pair represents radial, righthand tangential face.]

In the case of Ash, a slight increase in strength with decreasing height appears to take place even before the cube form is reached, while with Longleaf Pine the cube still gave as low values as longer pieces. Why a block shorter than the cube should be stronger is not fully explained; it appears, however, that the form of failure in the shorter blocks differs usually from what appears to be the normal as best seen in specimens of Ash. In Diagram 1 Figs. 1 and 4 show what is here considered the typical form of failure in well-selected *quarter-sawed* material of Ash, while Figs. 2, 3, and 5 show forms of failure observed in blocks shorter than cubes in which, however, there occurs a great variation. Fig. 4 shows the normal failure, which seems to prevail in blocks longer than cube, namely, a failure identical in the angle of rupture on the tangential side with that of a cube. Two of the faces of each block are represented side by side.

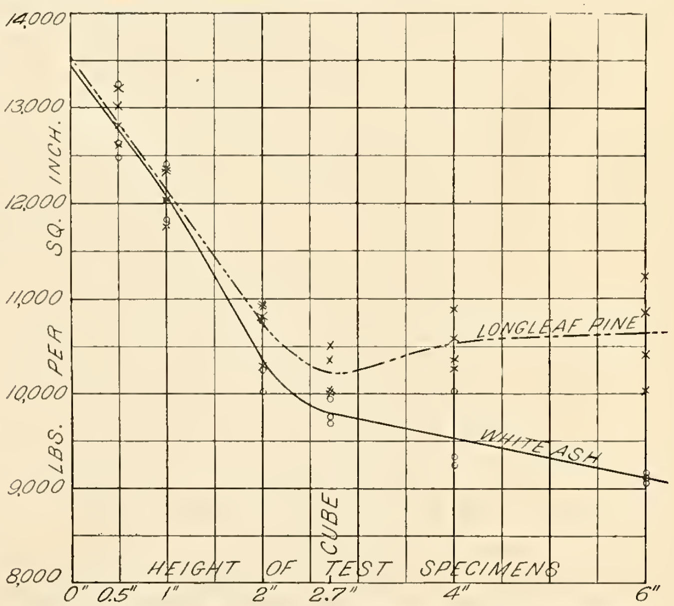


Diagram 2.—Influence of height of test specimen on strength in comparison.

This fact, that only perfectly quarter-sawed material exhibits this normal form of failure while bastard-sawed material shows varying forms, speaks strongly in favor of having all precise experiment in wood testing performed on quarter-sawed material. In addition, the material should be straight grained, a condition of which one can only make sure by splitting a sample of all test pieces. Slight deficiencies in workmanship do not influence the result materially. For instance, a planing of the end faces is unnecessary; all that is needed is an ordinary good square saw cut.

If a difference of only 5 per cent in strength values be ignored as the result of an unavoidable lack of uniformity in wood and of error in testing (see page 5), the fact that only blocks less than the cube show an appreciable influence of size is apparent from the data.

From another series it was apparent that satisfactory results can be obtained from blocks 2 by 2 by 2½ inches, and that even blocks of 1 by 1 by 2 inches may be relied upon for compression tests.

The following table and foregoing diagram illustrate the results of this series:

TABLE I.—*Variation in strength of wood in compression endwise caused by differences in height of test pieces.*

Method of sawing.

LONGLEAF PINE.

Dried at 75° C. Specific gravity = 0.54.
Number of rings per inch = 28.
Average strength = 10,210 pounds per square inch.
Cross section of blocks = 2¾ by 2¾ inches.

Number of scantling.	Compression strength for various heights of blocks.					
	½-inch.	1-inch.	2-inch.	2.76-inch cube.	4-inch.	6-inch.
	Lbs. per sq. in.	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq in.*
1	12,710	(*)	11,580	9,240	10,490	10,390
	(*)	11,880	11,160	9,800	10,790	10,600
	(*)	11,820	11,390	10,410	10.280	(*)
	12,590	(*)	10,210	10,090	9,900	9,780
	13,180	12,460	10,390	10,460	11,410	10,880
Average	12,820	12.050	10,950	10,000	10,570	10,410
2	14,280	12,520	10,230	10,630	10,230	10,590
	12,640	11.730	9,880	10,140	10,200	11,360
	12,410	12,310	10,320	10,720	(*)	11.410
	13,490	12,810	10,720	10,610	10,610	11,580
Average	13.200	12,340	10.290	10,520	10,350	11.230
3	12,390	12,790	11,080	9,490	11,000	10.180
	11,960	10,760	(*)	10,590	(*)	10,300
	13,220	11,810	10,980	10,360	10,000	10,140
	12,860	12,120	10,360	9,680	9,810	9.500
Average	12,610	11,870	10,800	10,030	10,270	10,030
4	11,660	11,680	10,790	10,130	10,060	10,710
	13,360	12,210	10,520	10,520	10,880	11,180
	12,810	11,940	10,780	10,430	10,960	10,130
	13,010	12,410	10,810	(*)	10,960	(*)
	(*)	13,560	12,000	(*)	11,600	11,410
Average	12,710	12,360	10,980	10,360	10,890	10,860
Total average	12,840	12,150	10,750	10,230	10,520	10,630

WHITE ASH.

Dried at 75° C. Specific gravity = 0.60.
Number of rings per inch = 8.
Average strength = 9,790 pounds per square inch.
Cross section of blocks = 2¾ by 2¾ inches.

Number of scantling.	Compression strength for various heights of blocks.					
	½-inch.	1-inch.	2-inch.	2.76-inch cube.	4-inch.	6-inch.
	Lbs. per sq. in.	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
1	13,120	12,000	9,830	9,880	9,880	9.030
	(*)	12,220	10,220	9,890	9,170	9.020
	12.640	12,140	9,790	10,010	9,130	(*)
	12,090	11.780	10,240	10,000	9,160	(*)
Average	12,620	12,030	10,020	9,940	9,330	9,050
2	12,380	12,460	9,870	9,890	9,450	9,310
	(*)	11,630	10,330	9,610	9,130	9,380
	12,450	11,620	10,410	9.500	9,000	8,960
	12,610	11,610	10,410	9,730	9,390	9,010
Average	12,480	11,830	10,250	9,680	9,240	9,160
3	13.380	12.810	11,040	9,960	(*)	8,870
	(*)	12,180	10,520	9.580	10,360	(*)
	13,120	12,540	10,740	9.750	9,840	9,830
	(*)	12,120	10,790	9,720	9,890	8,620
Average	13.250	12,410	10,770	9,750	10,030	9,110
Total average	12,780	12,090	10,350	9.790	9,530	9,110

* Defective test.

TESTS FOR UNIFORMITY.

Scantlings of air-dry material, 6 to 10 feet long, of White Pine, Longleaf Pine, Tuliptree (Poplar), and White Oak, and of perfectly green material of Loblolly Pine and Cypress, fresh from the saw, were cut partly into blocks 2 by 2 by 2¾ inches, but mostly into cubes of 2¾ inches. All material was quartersawed, carefully prepared, and in all cases treated alike, either perfectly green or dried together at the same temperature. Altogether 529 tests in endwise compression were made, namely, 100 on White Pine, 72 on Longleaf Pine, 99 on Loblolly Pine, 40 on White Oak, 115 on Tuliptree (Poplar), 103 on Cypress.

From these tests the following table of averages is derived, together with Diagram 3.

TABLE II.—*Average of tests for maximum uniformity.*

Name.	Moisture.	Average strength of all pieces.	Greatest difference in strength between adjoining pieces.		Greatest difference in entire scantling, i. e., 6-10 foot piece.
	Per cent.	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Per cent.*	*Per cent.*
White Pine (Pinus strobus)	8	4,900	190	3.8	18
Longleaf Pine (Pinus palustris)	7.8	10,800	380	3.5	10
Tuliptree (poplar) (Liriodendron tulipifera)	8	6,010	480	8.3	20
White Oak (Quercus alba)	Yard dry.	8,300	1,110	13.4	37
Loblolly Pine (Pinus tæda)	125+(green).	2,670	130	4.8	20
Cypress (Taxodium distichum)	125+(green).	4,090	70	1.8	15

It will be observed that green Cypress excelled in its uniformity; that green Loblolly proves not more uniform than dry White and Longleaf Pine; that wood of the conifers far excel even the Tuliptree (poplar) with its uniform grain and texture; and that oak, as might be expected, is the least uniform. It will also be noticed that even in one and the same short scantling (6 to 10 feet) of select, quartersawed, Longleaf Pine differences of 10 per cent may occur, and that in all others these differences were even greater.

Incidentally in this and the following experiment a small number of the blocks were thoroughly oven-dried (to about 2 per cent moisture), and it was found that the strength of both Cypress and Loblolly was increased by about 150 per cent during drying, so that wood at 2 per cent is about two and one-half times as strong as perfectly green or soaked material; and also that drying from 8 to 10 per cent to the lowest attainable moisture condition (1 to 2 per cent) still adds about 25 per cent to the strength of the wood.

In the following diagram and table a part of the results are presented in detail:

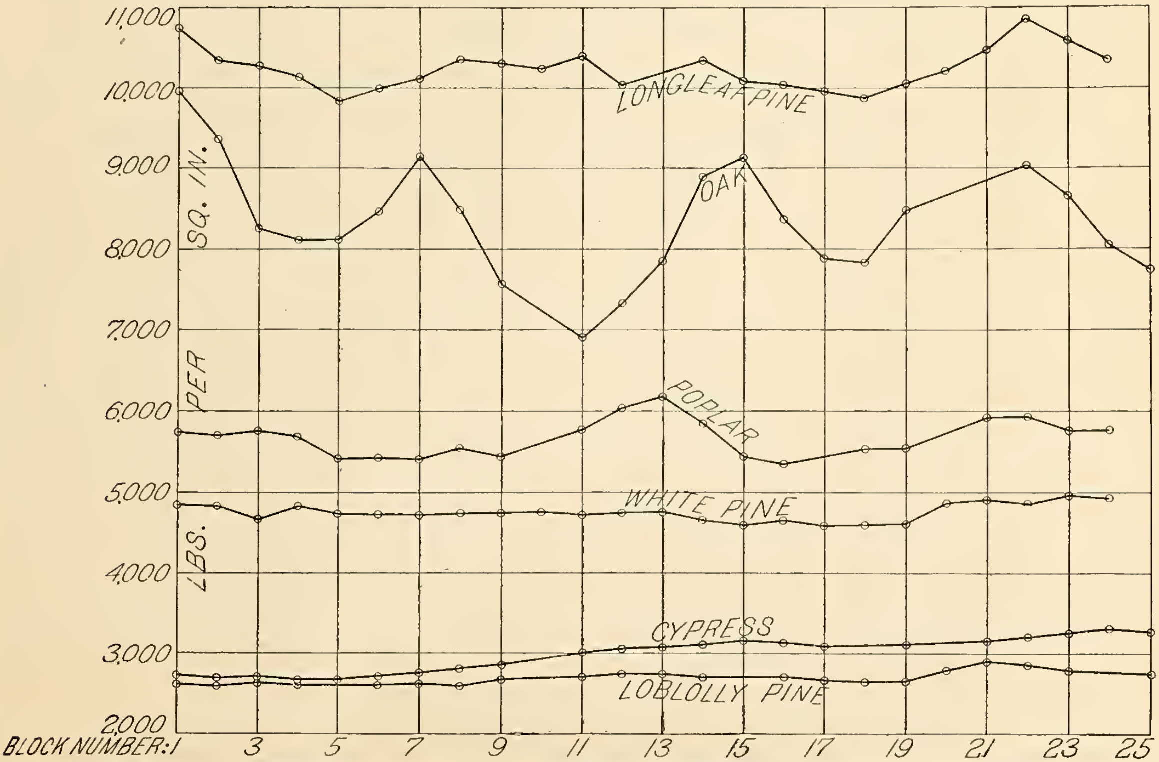


DIAGRAM 3.—Strength of contiguous blocks showing maximum uniformity of seclect quarter-sawed material in compression endwise.

TABLE III.—*Strength of contiguous blocks of the same scantling, select material, in compression endwise.*

[Dimensions generally, 2.76 by 2.76 by 2.76 inches.]

Number of blocks.	Kind of wood.						
	White Pine (8 per cent moisture).	Longleaf Pine (8 per cent moisture).	Loblolly Pine (125+ per cent moisture).	Cypress (125+ per cent moisture).		Tulip tree (8 per cent moisture).	Oak (yard dry).
	Pounds per square inch.						
1	4,850	11,580	2,330	2,720	4,170	5,740	9,970
2	4,860	11,530	2,380	2,700	4,190	5,700	9,370
3	4,690	11,310	2,380	2,720	4,170	5,770	8,260
4	4,840	11,060	2,450	2,680	4,180	5,700	8,120
5	4,760	8,250	*5,700	2,680	4,200	5,430	8,120
6	4,720	10,740	2,600	2,720	4,180	5,430	8,480
7	4,730	11,180	2,680	2,770	4,230	5,420	9,150
8	4,760	11,220	2,640	2,820	....	5,560	8,500
9	4,750	10,980	2,720	2,870	....	5,440	7,580
10	4,770	11,130	*6,970	....	....	*7,070	....
11	4,730	11,510	2,770	3,020	4,230	5,770	6,910
12	4,760	11,490	2,730	3,070	4,180	6,030	7,340
13	4,770	11,320	2,780	3,090	4,130	6,170	7,870
14	4,670	11,220	2,800	3,120	4,160	5,840	8,900
15	4,600	11,320	*5,840	3,170	4,160	5,440	9,130
16	4,660	11,340	2,880	3,140	4,160	5,360	8,380
17	4,590	11.470	2,870	3,090	4,110	....	7,890
18	4,600	10,790	2,870	....	4,090	5,530	7,840
19	4,610	10,740	2,860	3,120	4,070	5,530	8,480
20	4,880	11,030	*6,480	....	....	*6,880	....
21	4,920	11,110	2,760	3,170	....	5,920	....
22	4,870	11,450	2,760	3,220	....	5,930	9,030
23	4,970	12,250	2,720	3,270	....	5,770	8,660
24	4,940	12,760	2,640	3,320	....	5,780	8,060
25	....	10,740	*7,050	3,270	....	6,120	7,740
26	5,070	10,350	2,680	....	....	6,480	7,580
27	4,940	10,280	2,650	3,320	....	6,310	8,400
28	5.020	10,150	2,650	3,370	....	6,220	8,710
29	5,110	9,860	2,780	3,420	....	6,310	8,060
30	5,020	10,000	*7,320	....	....	*7,420	....
31	4,950	10,120	2,730	3,490	....	6,340	7,280
32	4,820	10,370	2,780	3,520	....	6,360	7,510
33	4,950	10,320	2,720	3,570	....	6,040	7,510
34	4,900	10,250	2,660	3,620	....	....	8,080
35	5,040	10,400	*5,360	3,640	....	6,280	9,030
36	5,160	10,050	2,610	....	....	6,490	8,790
37	5,120	10,050	2,560	....	....	6,610	8,640
38	5,100	10,350	2,580	....	....	6,220	8,560
39	5,230	10,100	2,580	....	....	6,190	8,780
40	5,280	10.030	*5,220	....	....	*7,300	....
41	5,260	9,970	2,620	....	....	6,010	....
42	5,280	9,880	2,600	....	....	6,140	....
43	5,300	10,050	2,640	....	....	6,170	....
44	5,310	10,220	2,610	....	....	6,010	....
45	5,300	10,470	*6,440	....	....	6,490	....
46	5,350	10,860	2,620	....	....	....	....
47	5,400	10,590	2,620	....	....	6,080	....
48	5,360	10.350	2,600	....	....	5,860	....
49	5,360	11.150	2,680	....	....	6,110	....
50	5,510	10,970	*6,440	....	....	*7,920	....
51	5,070	10,890	2,710	....	....	6,210	....
52	5,150	10,790	2,750	....	....	6,270	....
53	5,020	10,970	2,760	....	....	6,300	....
54	4.770	11,040	2,720	....	....	6,420	....
55	4,770	10,940	*6,850	....	....	6,450	....
56	4,920	10,970	2,710	....	....	6,170	....
57	4,950	10,840	2,680	....	....	6,440	....
58	4,840	10,710	2,660	....	....	6,340	....
59	4,860	10,890	2,660	....	....	6.310	....
60	*6,460	10,710	*7.030	....	....	*7,540	....

* Dried to about 2 per cent moisture before testing.

EFFECT OF WATER SOAKING.

A series of 132 compression endwise tests on pieces of White Pine, Longleaf Pine, Tuliptree (Poplar), Oak, and Ash made in the same manner as the preceding, but on material which had been yard dry and then soaked in cold water for over four months, showed that this soaked material behaved very much like the green material, displayed but little less uniformity, and that the difference between soaked and dry material was about the same as between green and dry material. For purposes of investigation the green material was found preferable to soaked pieces, since much time is lost in soaking and a uniform distribution of moisture not readily attainable.

A more thorough study of the quantitative influence of moisture on the strength of material, the need of which has so strongly been emphasized by the few tests made in connection with the previous series, had been fully planned but had to be abandoned.

EFFECT OF COMPRESSION ACROSS GRAIN ON COMPRESSION ENDWISE STRENGTH.

To answer the repeated inquiries as to the behavior of wood when being crushed across the grain, and thus to ascertain the proper factor of safety to be allowed in this particular use of wood material, a few preliminary tests were made to help in planning a more extensive series. From the few experiments made on White Pine, Longleaf Pine, and Ash it appears that the resistance of the material not only increases considerably when the deformation has passed beyond 3 per cent—the limit adopted by Sharpless (see Vol. IX, Tenth Census) and also employed in the tests for this division—but that it increases up to 50 per cent and more; i. e., a 2-inch block of pine sustains a far greater load when compressed to 1 inch than it sustained originally. But what seemed most remarkable was that blocks thus compressed more than 50 per cent of their original size, whether parallel or vertical to the rings, proved about as resistant in endwise compression as if no deformation in compression across the grain had occurred, and that when blocks $2\frac{3}{4}$ inches were compressed to 1 inch and both form and coherence of the block seemed seriously disturbed, the strength in endwise compression per square inch was found fully as great as that of neighboring pieces which had not undergone any deformation.

The following cases fully illustrate the behavior of wood in these experiments, and some of the details are recorded in Table IV. Square pieces were split from the much distorted pieces and the dimensions of these are given in the portion of the table where a comparison is made between compressed and uncompressed pieces. To correlate these tests better the check pieces from wood not previously compressed were made about the same size as those compressed.

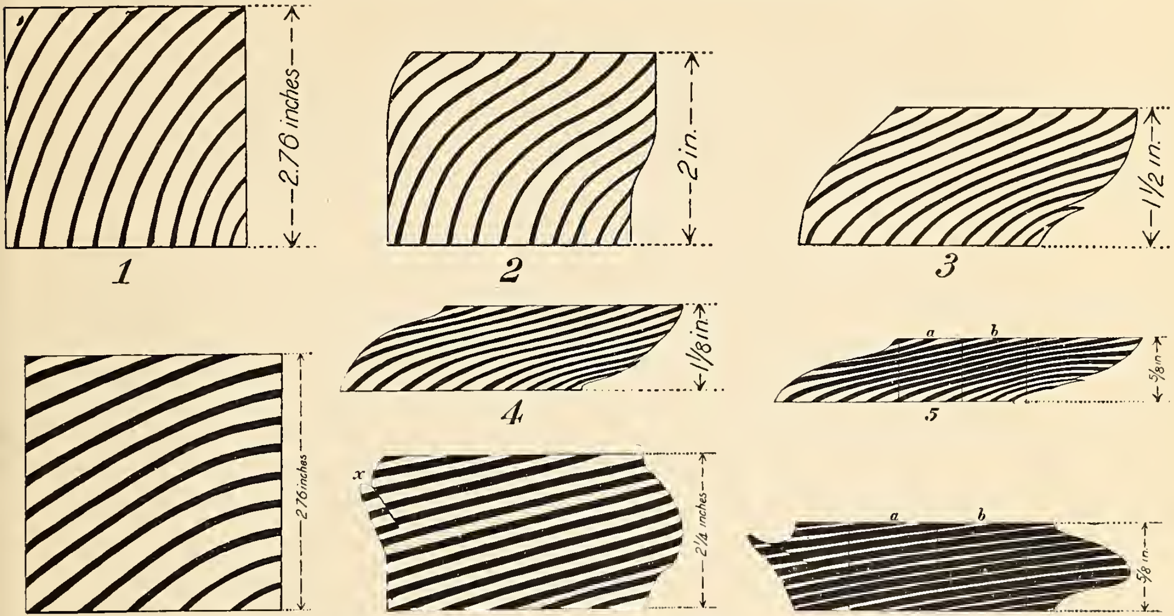
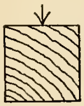
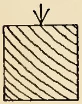
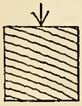
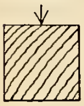
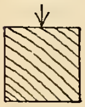


Diagram 4.—Behavior of wood in comparison across grain.

Table IV.—*Strength of White Pine in compression across the grain, and strength in compression endwise of pieces previously crushed across the grain to less than half their original size.*

Manner of loading.	Side of cube (inches).	Distortions, in per cent of original dimensions and corresponding total loads, producing such distortions, in pounds.						Strength in compression endwise.			
								Pieces crushed across the grain to over 50 per cent.		Check pieces not previously compressed.	
		3 per ct.	10 per ct.	18 per ct.	27 per ct.	45 per ct.	63 per ct.	Dimensions (inches).	Pounds, per square inch.	Dimensions (inches).	Pounds per square inch.
	2.76	3,700	3,800	4,600	5,100	7,900	12,900	1.46 by 3.16	5,020	1.10 by 1.07	4,760
	2.76	3,500	3,800	4,100	....	5,900	[1] 9,300	.98 by 1.02	5,700	1.00 by .99	5,250
	2.76	3,200	3,800	4,100	4,700	6,900	[2] 12,000	.94 by 1.10	5,100	1.09 by 1.02	5,200
	2.76	3,200	3,700	3,900	4,700	6,500	[3] 13,600	.96 by 1.05 .92 by 1.05	5,450 5,590	1.03 by 1.03	5,180
	2.76	3,400	3,700	4,100	4,800	7,100	[4] 15,000	1.00 by 1.05 1.00 by 1.05	6,570 6,090	1.01 by 1.05	5,280

[1] When compressed to ½-inch, the load sustained was 80,000 pounds; on release recovered to 0.93 inch.
[2] When compressed to ⅝-inch sustained 50,000 pounds; on release recovered to 1.1 inch.
[3] When compressed to ⅝-inch sustained 50,000 pounds; on release recovered to 1.05 inch.
[4] When compressed to ⅝-inch sustained 40,000 pounds; on release recovered to 1 inch.

Though these few tests are entirely inadequate to answer the important question of quantitative resistance of the different woods in compression across the grain, it will be of interest to know that this resistance is comparatively great, and that it increases with compression rapidly far beyond the limits usually assumed in testing.

INFLUENCE OF SIZE ON STRENGTH.

In Circular 12 of the Division of Forestry there was recorded a small series of tests on large-sized beams and a larger series on columns, which indicated that size by itself has but little influence on strength. A series more extended as regards beams, involving 68 large and 777 small beams, besides over 1,000 compression tests on the same material on which the beam tests were made, and tests on 6 large columns, has fully confirmed the indications of the previous experiments.

TESTS ON COLUMNS.

The columns were 12 by 12 inches and 8 by 12 inches in cross section, with a length of 132 to 168 inches. From these were cut as near as possible from the place of failure two blocks, 24 inches long, and these blocks were tested on the same large testing machine (described in Bulletin 6), so that inaccuracies of machinery do not enter into consideration. The results, tabulated as follows, prove conclusively the statement made upon the former more extensive series (see Circular 12), that wooden columns in which the diameter and length are to each other as 1 to 18 or less behave like short blocks and fail in simple compression. The four columns of Longleaf Pine exhibit practically the same strength as the short blocks—i. e., within 10 per cent—which, as has been shown above, is within the limits of maximum uniformity.

Table V.—*Strength of large columns and short (24-inch) blocks cut from these columns.*

Kind of wood.	Dimensions of columns (inches).			Moisture of wood (per cent).	Modulus of elasticity (pounds).	Compression strength in pounds per square inch.	
						Columns.	Short blocks.
Shortleaf Pine	144	12	12	14.2	2, 274, 000	4, 840	6, 090
Do	132	12	12	12.9	1, 740, 000	4, 840	5, 660
Longleaf Pine	168	12	8	30.9	1, 628, 000	2, 940	2, 950
Do	168	12	8	32.3	1, 570, 000	3, 170	3, 530
Do	156	12	8	40.8	1, 764, 000	3, 030	3, 310
Do	156	12	8	29.7	1, 776, 000	3, 710	3, 780

BEAM TESTS.

The experiments of which the following tables contain the principal results were performed on beams generally 8 by 12 by 192 inches. After breaking the large beam 12 small beams were cut from the uninjured portion of the large beam * in such a way that the entire cross section of the large piece was represented by two sets of 6 small beams each. (See diagram at head of Table VI.) Besides these tests on small beams, the compression strength of part of the material was tested on small blocks, part of which was sawed and part split from portions of the large beam. (See diagram at head of Table VI.) To avoid any complications due to differences or changes in moisture, the tests on large and small beams were performed the same day.

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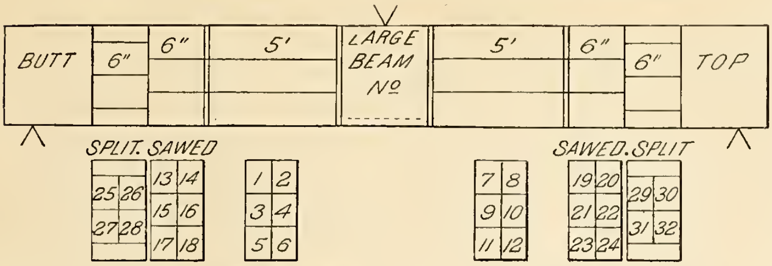
*The legitimacy of using such material for such purpose has been fully established by a long series of experiments. (See Circular 12, p. 11.)

Table VI.—*Strength of large beams and of small beams and of compression pieces cut from them.*

[Usually 12 small beams cut from the uninjured part of each large beam.]



Kind of wood.	Number of beam.	Strength of large beams.	Average strength of small beams.	Moisture.		Compression, endwise strength.	
				Large beams.	Small beams.	Sawed pieces.	Split pieces.
		Lbs. per sq. in.	*Lbs. per sq. in.*	*Per cent.*	*Per cent.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
Oak	1	7,400	8,560	69.5	68.5	3,960	4,120
	2	5,880	8,660	70.3	69.0	4,340	4,700
	3	6,570	6,220	75.3	75.2	3,030	3,190
	4	8,640	8,800	66.6	67.6	4,090	4,460
	5	8,150	7,710	64.8	65.8	3,680	3,750
	6	7,450	6,910	63.0	66.6	3,330	3,330
	8	6,870	6,890	67.4	70.5	3,470	3,190
Shortleaf Pine	9	8,300	7,950	48.1	57.7	4,030	4,160
	10	7,440	7,250	42.1	56.3	3,840	3,850
	11	5,110	6,760	38.9	33.3	3,870	3,630
	12	7,360	6.930	35.2	33.5	3,890	3,850
	13	7,320	7,300	37.4	40.6	4,090	3,800
White Pine	14	3,110	3,560	84.9	83.6	2,440	2,500
	15	4,280	4.340	43.8	41.2	2,710	2,840
	16	3,770	4,590	50.7	50.5	2,660	2,760
	17	3,460	3,590	60.0	48.6	2,410	2,570
	18	3,990	3,640	42.8	43.0	2,800	2,620
	19	4,040	4,400	62.4	60.4	2,760	2,780
	20	4,410	4,180	53.6	51.8	2,680	2,700
	21	4,900	4,320	50.1	51.0	3,010	2,900
	22	3,860	4,320	50.2	60.8	2,500	2,430
	23	4,660	4,890	52.0	58.2	2,850	2,880
	24	3.960	4,440	76.3	71.5	2.520	2,710
	25	3,920	4,410	53.6	60.5	2,840	2.730
Shortleaf Pine	26	4,560	6,290	31.2	30.5	3,660	3,850
	27	4,390	5,610	33.9	36.0	2,830	3,110
	28	6,670	6,830	28.6	28.9	3,540	3,590
	29	7,410	7,630	28.6	29.0	4,450	4,250
	30	6,600	7,160	28.3	28.9	4,200	4,190
	31	5.750	6,000	34.3	35.5	3,630	3,530
	32	6,210	7,500	26.4	27.2	3,940	4,056
	33	7,450	8,390	29.5	30.1	4,350	4,220
	34	7,000	7,800	28.4	29.5	4,070	4.120
	35	6,030	6,740	28.8	29.4	3,810	3,640
	36	6,520	6.890	31.6	31.6	4,320	4,370
	37	7,030	7,890	29.2	29.9	4,380	4,920
	38	7,710	8,510	26.2	25.4	4,500	4,610
	39	8,090	8,210	32.5	31.9	4,550	4,670
	40	7,680	7,980	31.1	32.3	4.290	4,380
	41	7,330	8,230	31.7	31.5	4,680	4,820
Longleaf Pine	42	7,290	8,740	30.9	31.2	4,950	5,120
	43	8,850	9.720	28.1	28.9	5,300	5,440
	44	8,040	8,870	26.3	26.9	4,730	5,070
	45	8,090	8,850	25.8	25.4	5,000	5,050
	46	7,620	7,670	32.6	33.9	4,730	4,830
	47	6,710	7,610	33.0	33.4	4,200	4,520
	48	8,480	8,300	29.3	29.3	4,870	4,890
	49	5,630	6,250	34.5	33.7	3,600	3,630

OBSERVATIONS AND DEDUCTIONS.

(*a*) The difference between the values for the large beam and the average for the small beams is not at all constant, either in character or quantity; the large beam may be stronger (20 per cent of the cases) or practically as strong, i. e., within 10 per cent (57 per cent of the cases), or it may be weaker and vary often considerably from the average (23 per cent of the cases).

Of 696 tests on small beams 235 furnished results smaller than that of the large beam. Again, out of 396 small beams, fully 40 per cent were weaker than the large beam, while of another series of 300 only 24 per cent gave lower values.

(*b*) There are in every case some small beams which far excel in strength the large beam; even in such cases where the average strength of the small beams is practically the same as that of the large beam, some small beams show values 25 to 30 per cent greater than the large beam.

(*c*) In only 6 per cent of the cases each of the small pieces gave a higher result than was obtained from the large beam, but in these cases the latter was evidently defective.

(*d*) In all beams the differences observed between the several small beams themselves are far greater than that between the average value of the small beams and the value of the large beam from which they are cut.

From these observations, which are fully in accord with the observations on the numerous tests of the large general series, it would appear that—

(1) Size alone can not account for the differences observed; and, therefore, also that a small beam is not proportionately stronger because it is smaller,

TABLE VI.—*Strength of large beams and of small beams and of compression pieces cut from them*—Continued.

[Usually 12 small beams cut from the uninjured part of each large beam.]

Kind of wood.	Number of beam.	Strength of large beams.	Average strength of small beams.	Moisture.		Compression, endwise strength.	
				Large beams.	Small beams.	Sawed pieces.	Split pieces.
		Lbs. per sq. in.	*Lbs. per sq. in.*	*Per cent.*	*Per cent.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
White Pine......	50	4,900	5,020	87.2	75.7	2,970	3,200
	51	5,300	5,210	71.4	69.6	3,330	3,240
	52	4,810	4,470	77.2	64.7	2,940	3,100
	53	3,610	3,610	54.5	58.2	2,400	2,550
	54	4,440	4,720	97.6	94.9	2,710	2,900
Shortleaf Pine...	55	6,400	7,610	27.0	27.1	4,340	4,500
	56	6,690	6,880	28.4	26.6	4,050	4,210
	57	6.670	6,990	27.0	26.4	4,100	4,340
	58	7,310	7,490	28.5	26.8	4,100	4,030
White Pine......	101	5,070	7,200	15.4	16.2	5,410	5,720
	102	6,340	6,890	11.0	11.7	4,920	5,520
	103	7,070	8,750	12.2	10.5	5,140	5,760
	104	4,900	6,680	12.1	8.2	4,360	4,700
	105	6,640	6,890	10.6	11.2	5,450	5,310
	106	6,180	7,650	11.6	11.3	5,190	5,420
	107	6,080	6,090	11.5	11.5	4.810	5,170
	108	5.510	5,810	11.1	10.7	5,100	4,710
	109	6,930	7,300	11.4	10.5	5.330	5,080
	110	5,930	6,010	12.1	11.6	4,600	4,670
	111	4,010	5,040	13.0	13.0	4,270	4,390

for it may be either stronger or weaker; but that if it is stronger, the cause of this lies in the fact that the larger beam contains weak as well as strong wood, besides other defects which may or may not appear in the small stick.

(2) Generally, but not always, a large timber gives values nearer the average, since it contains, naturally, a larger quantity as well as a greater variety of the wood of the tree; and, therefore, also:

(3) Small beams, for the very reason of their smallness, containing, as they do, both a smaller quantity and variety of the material, give results which vary more from the average than results from large beams, and, therefore, can be utilized only if a *sufficient number* be tested; but it also appears that:

(4) To obtain an average value, even a very moderate number of smaller pieces, if they fairly represent the wood of the entire stem, give fully as reliable data as values derived from a large beam.

(5) *Average values derived from a large series of tests on small but representative material may be used in practice with perfect safety, and these averages are not likely to be modified by tests on large material.*

It might be added that both the practicability and need of establishing a coefficient or ratio between results from tests on large and small beams or columns falls away. To deserve any confidence at all, only a large series of tests on either large or small beams would satisfy the requirement of establishing standard values, while a series of small pieces has the preference, not only on account of greater cheapness and convenience in establishing the values, but still more for the reason that only by the use of small, properly chosen material is it possible to obtain a sufficiently complete representation of the entire log.

DISTRIBUTION OF MOISTURE.

To increase our knowledge of the distribution of moisture in wood throughout the length and cross section of the stick a new series of experiments was made.

For the purpose of determining moisture distribution through the length of a stick, six scantlings of each of six species of wood, 4 by 4 inches cross section, pronounced "yard dry," were cut up, as shown at the head of Table VIII. A few scantlings were taken from an ordinary dry kiln and then dried in the oven with the results given in the last three columns of Table VII.

Each of the disks 1, 2, 3, 4, 5, 6, 7, and also borings (No. 8 in table) from disk 9, were dried in a sheet-iron oven 2 by 2 by 5 feet at 80° C. until their weight became constant. It was found that by shifting the disks in the oven from hotter to cooler parts a difference in dry weight could be effected which might vary the result by 1.2 per cent. Such a difference, therefore, must be considered an error of apparatus.

TABLE VII.—*Distribution of moisture—average results.*

	Per cent of moisture in weight of dry wood								
	Yard dry.						Kiln dried.		
	Long-leaf Pine.	Red Oak.	Tulip tree.	White Pine.	Ash.	Cy-press.	Tulip tree.	White Pine.	Ash.
Average for the entire stick	27.8	24.8	14.2	14.8	13.6	54.1	7.2	6.4	6.4
Maximum for the entire stick	30.5	28.9	15.4	17.8	15.1	64.9	8.4	8.8	8.0
Minimum for the entire stick	26.5	23.6	13.2	13.2	12.9	52.0	5.3	4.4	4.9
Greatest range	4.0	5.3	2.2	4.6	2.2	12.9	3.1	4.4	3.1
Greatest difference between two adjoining disks	2.4	2.0	1.4	2.1	1.1	3.7	1.3	2.2	1.9

As deductions or results of the more than 1,100 determinations it can be stated:

(1) That with the ordinary oven and methods in use a difference of 1.2 per cent in moisture may be charged to defective method, or, in other words, may be neglected as a possible error.

(2) That the distribution of moisture from one end of a stick to the other is quite uniform in yard dry material although the extreme ends may be fully 10 to 13 per cent drier than the middle. This great difference is noticeable only for the first 2 inches in a stick of 4 by 4 inches, while consecutive sections, even in sticks with over 25 per cent moisture, generally differ by less than 1 per cent and only in exceptional cases by as much as 3 per cent. In wood dried in ordinary kilns (5 to 7 per cent moisture) the ends still differ for a distance of 2 inches from the main body of the scantling by over 3 per cent moisture, and after that the consecutive disks even here differ some times by as much as 2 per cent, though generally by less than 1 per cent. In green material, as might be expected, a wide range of values can exist, which is greatest where sap and heart are both represented, and smallest where only heart wood is under test. The differences in green wood, however, are of no importance in immediate use of the material, and can affect the case only in so far as they influence the distribution of moisture during drying.

(3) That the experiments show that the determination for moisture is best made on disks or cross sections at least ½ inch thick, and that borings are the most unsatisfactory form of all, since they not only fail to represent fairly the cross section of a timber but are also subject to loss of woody matter and moisture during the process of determination.

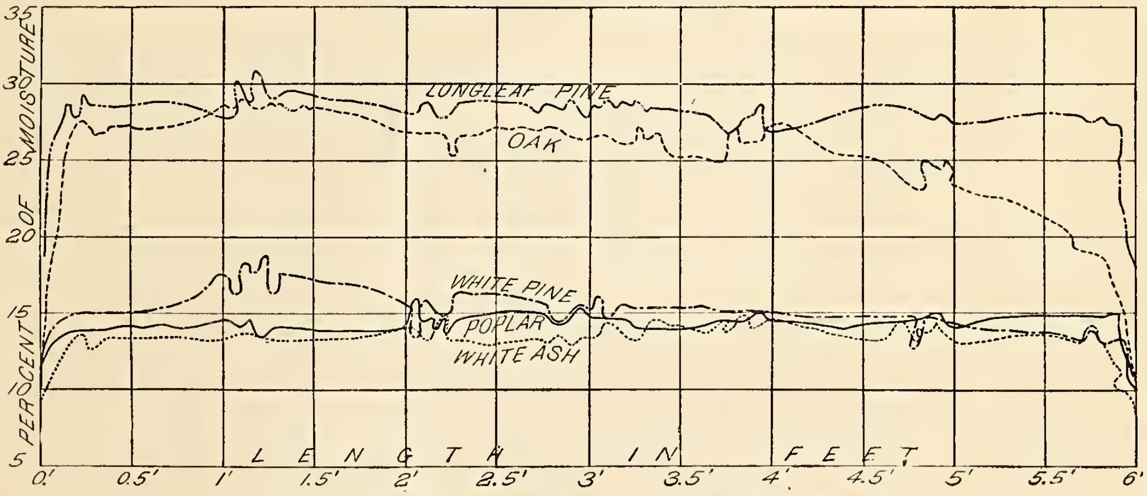
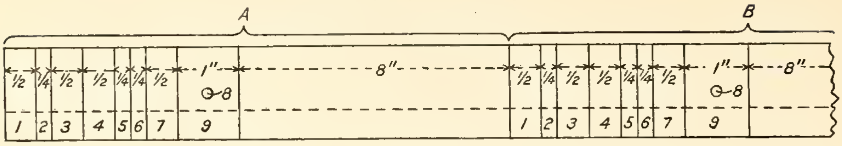


DIAGRAM 5.—Distribution of moisture thoughout the length of a scantling.

TABLE VIII.—*Distribution of moisture—Part of results in detail.*

METHOD OF SAWING.



Mark and number of disks.		Moisture as a per cent of the weight of the dry wood.								
		Long-leaf Pine.	White Oak.	Poplar.	White Pine.	Ash.	Cypress.	Ash.*	Poplar.*	White Pine.*
A	1	22.0	11.2	12.9	10.1	10.9	15.0	5.8	6.0	4.5
	2	27.1	16.9	13.4	11.5	12.1	25.5	4.3	5.4	2.9
	3	28.3	20.9	13.4	13.8	12.4	29.2	5.1	5.6	4.3
	4	30.0	24.8	13.2	14.0	13.4	35.9	4.4	5.6	4.2
	5	30.0	27.1	13.3	13.1	13.7	35.1	4.8	4.5	2.3
	6	30.0	27.5	12.4	15.1	13.2	38.1	4.3	6.4	2.3
	7	30.0	26.3	13.6	15.2	13.6	40.1	5.1	6.2	2.3
	8 boring	32.7	34.0	10.6	13.2	22.6	55.8	9.0	8.4	1.7
	9	....	26.9	....	....	13.8	43.7	4.8	6.4	3.9
B	1	....	28.8	14.1	17.4	14.2	58.2	5.9	7.2	5.1
	2	29.5	29.9	14.6	16.5	13.8	56.2	5.0	6.4	5.4
	3	31.0	28.7	14.0	18.2	14.1	55.1	5.8	7.4	5.0
	4	30.0	28.5	15.0	17.8	14.2	56.1	6.3	7.1	6.2
	5	33.3	28.5	14.5	18.4	14.4	55.2	5.6	6.3	5.6
	6	30.0	29.3	14.6	16.6	13.7	56.7	4.6	6.9	4.4
	7	30.0	28.1	14.1	17.1	14.4	55.8	5.5	7.1	6.3
	8 boring	23.3	40.5	18.0	18.1	19.6	75.9	7.0	8.4	3.6
	9	....	28.7	....	....	13.9	53.8	6.6	7.5	7.1
C	1	28.7	27.4	14.7	15.7	13.4	55.0	6.6	7.2	5.4
	2	29.0	27.7	14.0	13.6	13.5	55.9	5.9	6.9	3.5
	3	28.8	28.0	14.2	16.1	12.8	56.2	6.6	6.9	5.6
	4	29.5	27.6	14.4	15.4	13.0	58.2	6.5	7.5	6.8
	5	28.5	28.8	13.4	15.6	13.9	58.9	5.8	7.6	4.1
	6	28.9	26.4	13.6	14.2	....	59.0	5.6	7.5	5.0
	7	28.7	28.6	14.1	16.2	12.9	59.0	6.3	7.5	6.4
	8 boring	31.5	40.5	15.5	13.8	19.3	86.2	7.9	8.4	3.6
	9	....	27.0	....	....	13.8	58.2	6.1	7.2	7.4

* Dried first in an ordinary commercial dry kiln.

The distribution of moisture throughout the cross section (transversely) is far less even and regular than through the length (longitudinally), a fact which is, apparently, due to peculiarities in the structure of wood. Thus, in a 4 by 4 cypress, with an average of 45 per cent, the corners may have but 18 per cent, the middle sides 60 to 80 per cent, and the center over 100 per cent of moisture, and similar conditions obtain in case of oak and pine. Diagram 6 exhibits this distribution in case of a scantling of Longleaf Pine (a) and Cypress (b), the numbers representing actual moisture per cent.

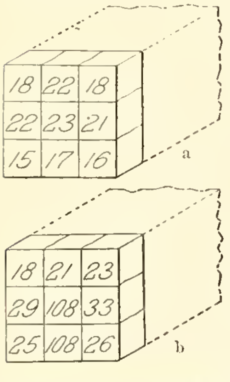


DIAGRAM 6.—Distribution of moisture throughout cross section.

RATE AND CONTROL OF ABSORPTION OF MOISTURE.

For a more detailed examination into the influence of moisture on the strength of wood, it has appeared desirable to control the moisture per cent either by the drying of the material or by the absorption of water by test material in order to test at definite per cents of moisture. To ascertain how far this is practicable a special series of experiments has been carried on during the year, which proved clearly that the rate of absorption is readily controlled in White and Longleaf Pine, and also in Cypress; and it appears that, with blocks of White Pine 1 by 2 inches and 2 inches in length, the state of 4 per cent moisture is regained on shelf and at an ordinary temperature in 6 days after leaving the kiln; 8 per cent moisture may be attained in 24 hours by placing the pieces in a tray and surrounding this latter with damp sacking, and that 16 per cent is reached in

5 days under similar conditions. Wrapped in damp cloth, similar blocks reached 9 per cent in 24 hours and 30 per cent in 26 days, and the rate of absorption was amply slow to enable a satisfactory control after 20 per cent moisture was replaced.

STRENGTH OF BEAMS, DETERMINED FROM COMPRESSION STRENGTH.

When the writer, in 1891, organized the comprehensive work of timber physics in the Division of Forestry, planned several years before, he realized that the large series of data resulting from the many different kinds of tests, while necessary, would be difficult to handle and correlate; but he also foreshadowed the possibility of finding such a relation between the same as to reduce the number of tests necessary. This hope was expressed in the following sentence in Bulletin 6, page 30, 1892, when discussing this line of work:

> By and by it is expected that the number of tests necessary may be reduced considerably, when for each species the relation of the different exhibitions of strength can be sufficiently established, and perhaps a test for compression alone furnish sufficient data to compute the strength in other directions.

It is, therefore, with great gratification that the writer may now announce that the expectation then expressed is now realized.

A careful study of the accumulated data by Mr. S. T. Neely disclosed such a constant proportionality between the compression and cross-bending strength that he was led to investigate the same more closely. His studies have enabled him to elucidate not only the true position of the neutral plane in beams, which had hitherto been in doubt, but also to develop the formula for a practically correct correlation between compression and cross-bending strength, both at the elastic limit and at rupture. The results, we believe, will be of far-reaching importance, both to the science of wood and wood testing and to the practice of using test data in designing structures.

It would appear that the strength of a beam at the (true) elastic limit—the only strength value in which the practitioner is interested when designing beams—is equal practically to the compression-endwise strength of the material; that is to say, the compression strength is to be used for the factor (f) in the current beam formula ($W=\frac{2bh^2}{3l}f.$)

We expect, finally, after further verification of the discovered correlation, that compression tests alone may suffice in future to determine all strength values of the material; that the designing of beams will be accomplished upon such data with much more confidence; that the factor of safety will be brought to a rational basis, and that greater economy in the use of wood will also be secured.

To assure the full credit of this important discovery to Mr. Neely, the discussion of the same is here given in his own words.

RELATION OF COMPRESSION-ENDWISE STRENGTH TO BREAKING LOAD OF BEAM.

By S. T. Neely, C. E.

In testing timber to obtain its various coefficients of strength, the test which is at once the simplest, most expedient, satisfactory, and reliable is the "compression-endwise test," which is made by crushing a specimen parallel to the fibers. All other tests are either mechanically less easily performed, or else, as in the case of cross-bending, the stresses are complex, and the unit coefficient can be expressed only by reliance upon a theoretical formula the correctness of which is in doubt. It would, therefore, be of great practical value to find a relation between the cross-bending strength, the most important coefficient for the practitioner, and the compression strength, when the study of wood would not only be greatly simplified and cheapened, but the data could be applied with much greater satisfaction and safety.

The consideration of such a relation resolves itself naturally into two parts, namely, a study of the relation of the internal stresses in a beam to the external load which produces them, and a study of the relation of the internal stresses in a beam to the compression-endwise strength of the material of which the beam is made.

The first relation has been a subject of study for more than two centuries, and from the time of Galileo down to the present day the theory of beams has been gradually evolved. Within recent years several eminent physicists and engineers have given a true analysis of both the elastic and ultimate strength of a beam, a clear exposition of which is made by Prof. J. B. Johnson in his work on "Modern Framed Structures." He points out that the "ordinary equation" for obtaining the extreme fiber stresses, when the external load and dimensions of the beam are given, is *not* applicable to a beam strained beyond its elastic limit, and he follows this statement with a discussion of the true distribution of internal stresses in a beam at time of rupture, and with a "Rational equation for the moment of resistance at rupture," devised by M. Saint-Venant, which really does connect the extreme fiber stress in a bent beam with the compression-endwise strength and also with the tension strength. Professor Johnson's final conclusion, however, is that for practical use the "ordinary formula" may be applied to a beam at rupture providing the fiber stress involved is obtained from cross-bending tests; and this is the present practice among engineers.

RELATION OF INTERNAL STRESSES.

Assume for the discussion of the relation of internal stresses to external load the simple conditions of a beam of rectangular cross section loaded at the middle.

Regarding the distribution of internal stresses, it must be agreed that the neutral plane lies in the center of the beam so long as the beam is loaded within the elastic limit; this follows from the fact that the modulus of elasticity is the same whether derived from compression tests or from tension tests (i. e., $E_c = E_t$), as proved by experiments of Nördlinger, Banschinger, Tetmayer, and others.

Since the distortion of any given fiber in the beam is proportional to its distance from the neutral plane, the distribution of stresses in a longitudinal section of a beam loaded up to its elastic limit may be represented by the following diagram, in which the vertical scale represents increments of distortion and the horizontal scale the fiber stresses.

In this diagram the angle a = angle b, since $E_c = E_t$, and furthermore, since these latter quantities are each equal to the modulus of elasticity obtained from cross bending tests (according to the same authorities), this angle a (or b) can be obtained by plotting the results of the cross-bending test itself.

It is a well-established fact that the tension strength of wood is much greater than the compression strength, and also, as shown by the German experimenters quoted, that the elastic limit in either case is not reached until shortly before the ultimate strength. Furthermore, it seems reasonable to suppose, and is essential to the construction of the above diagram, that the *true elastic limit* of the beam (shown on the strain diagram of a beam at the point where it ceases to be a straight line) is reached at the same instant that the elastic limit of the extreme compression fiber is reached; for when the loading is continued beyond this latter condition the line OC must begin to curve upward (since the proportion of load to distortion on that side begins to increase more rapidly), while the line OT continues in its original direction. Therefore, in order to maintain the equilibrium the whole distribution of stresses will necessarily be changed, the position of the neutral axis will be lowered, and these changes will of course show an effect on the deflection of the beam.

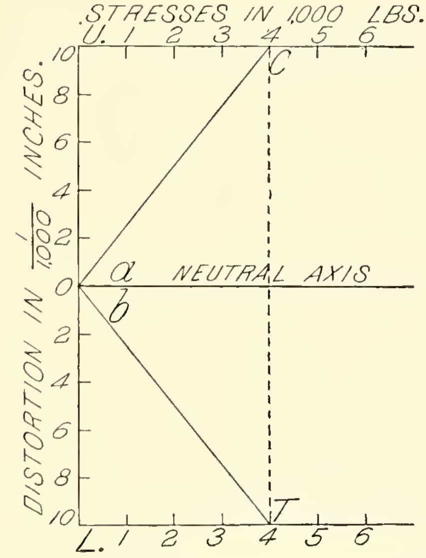


DIAGRAM 7.—Relation of fiber stresses and distortions.

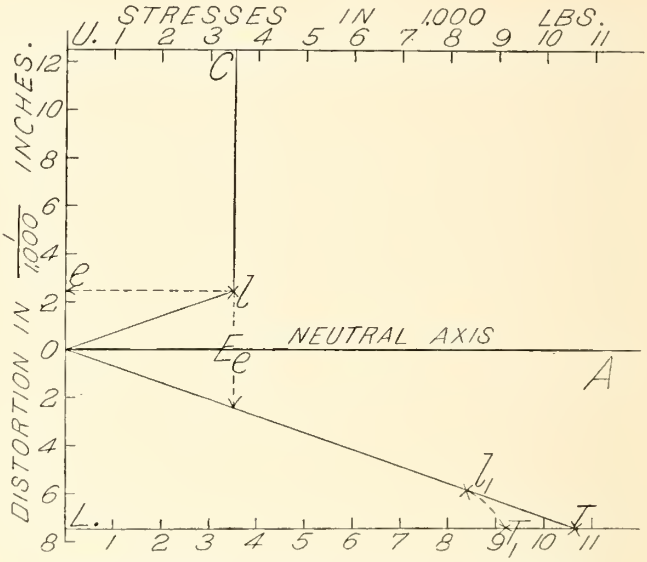


DIAGRAM 8.—Distribution of internal stresses in a beam at rupture.

Now, even at rupture the proportionality of fiber distortion to distance from neutral axis is maintained (because a plane cross section will always remain a plane), and therefore the distribution of internal stresses just at the point of rupture can be represented by a diagram similar to No. 8, in which, as before, the vertical scale represents increments of distortion and the horizontal scale fiber stresses. The fibers on either side of the neutral plane are under stresses which vary from zero at the neutral plane to the maximum stress in the extreme fiber, changing in proportion as the increments of load in the test machine vary. Therefore the distribution of stresses on the compression side of the neutral plane will be shown by an ordinary strain diagram for compression, and on the tension side by a similar tension-strain diagram. Unfortunately there are no reliable diagrams of these kinds now on record. The compression pieces tested have usually been too short to afford reliable measurements of distortion, and, owing to structural and mechanical difficulties, satisfactory tension tests seem to be impossible.

Experience in testing, however, has taught that when a piece of *green wood* is tested in compression it will undergo a great distortion after the maximum load has been applied *without actually breaking down*—in fact, while sustaining the same load. A piece tested in tension, on the other hand, breaks suddenly as soon as the maximum load is applied. A beam in failing may, therefore, sustain an increasing load long after the extreme compression fiber has been loaded to its ultimate strength; the fibers on the compression side continue to be mashed down, while the neutral plane is lowered and the stress in the tension fiber increases until, very often in practice, the beam "fails in tension." With these facts and observations before us it is possible to construct a diagram so that it will represent, approximately at least, the distribution of internal stresses in a beam at rupture. (See diagram 9.)

In this figure OA represents the position of neutral plane at time of rupture, OU the distortion in the extreme compression fiber, UC the stress on same fiber, OL the distortion in extreme tension fiber, and LT the stress on that fiber.

It can readily be seen that the manner of breaking will influence slightly the form of this diagram. If the beam fails in compression before the tension fiber reaches its elastic limit the line OT will be straight as shown, otherwise the line will assume some such position as Ol_1T, (diagram 8), in which l_1 is the elastic limit in tension.

From the approximate distribution of internal stresses their relation to the external load may be determined. The two fundamental equations—(1) that the sum of internal stresses on the tension side equals the sum of internal stresses on the compression side, and (2) that the sum of the external moments equals the sum of the internal moments,—apply at the time of rupture as well as at the elastic limit. From (1) it follows that area OUCl = area OLT and the position of the neutral plane at rupture is thereby fixed. If now the line LU be assumed to represent the depth of the beam in inches instead of indicating the distortion of the fibers, the sum of the internal moments about the point O is found by multiplying the area of either the compression or tension diagram by the sum of the distances of their respective centers of gravity from the neutral plane. By putting this sum equal to the moment of the external load about the same point O the first relation is established.

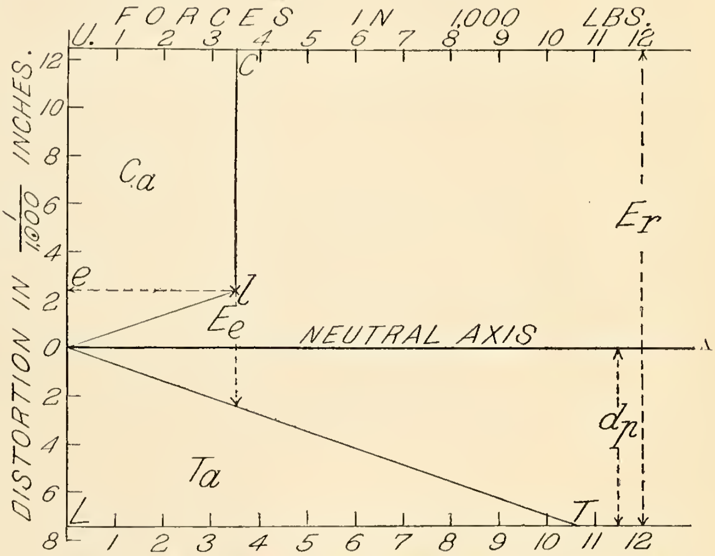


DIAGRAM 9.—Position of neutral axis and internal stresses at rupture of beam.

RELATION OF CRUSHING-ENDWISE STRENGTH.

The second relation (that of crushing-endwise strength to internal stresses) was touched upon in discussing the first, when it was stated: (1) That the true elastic limit of the beam is probably reached at the same instant that the extreme fibers on the compression side reach their elastic limit in compression. (2) That this latter limit lies close to the ultimate compression endwise strength (so close that former experimenters have been unable satisfactorily to separate them). (3) That a piece of green wood will stand a great deal of distortion after the ultimate load is applied before actually failing. And to these statements may be added the evident fact (4) that the stress on any fiber on the compression side *can not* exceed the compression endwise strength of the material. (5) Finally and most important it appears from (1) and (2) but especially from an examination of the several thousand test results on the several species of conifers made by the Division of Forestry, that *the extreme fiber stress at the true elastic limit of a beam is practically identical with the compression endwise strength of the material.* (This last observation, which was forced upon the writer by its continual repetition in the large series of tests under review, lies at the basis of this discussion). The observation of this identity makes the distribution of internal stresses appear more simple than was hitherto assumed and the desired relation between compression and cross bending strength capable of mathematical expression.

DEVELOPMENT OF FORMULÆ.

From these considerations the distance UC in diagram 9, which represents the ultimate compression endwise strength of the material, becomes practically equal to the distance *el*, which represents the compression strength at the true elastic limit, and hence the line lC straight and vertical; and if OT is taken as straight, the diagram will be made up of simple geometric figures, as in diagram 9

The line LU will represent the total fiber distortion at time of rupture, and is equal to the sum of the amounts by which the extreme compression fibers shorten and the extreme tension fibers elongate.

Let a test in which the following quantities have been observed and recorded be considered:

Let P_r = the external load at rupture (pounds).
Δ_r = the corresponding deflection of the beam (inches).
C = compression endwise strength of the material (pounds).
E = modulus of elasticity (pounds).
d = depth of beam (inches).
b = breadth of beam (inches).
l = length of beam (inches).
Δ_e = deflection at true elastic limit.

Then based upon the above statements, by means of formulæ derived from the geometric relations of the diagram and the fundamental equations of equilibrium, the following quantities can be calculated:

Let E_e = total fiber distortion due to bending at true elastic limit (inches).
E_r = total fiber distortion due to bending at rupture = LU (inches).
d_p = distortion in extreme tension fiber at rupture = LO (inches); also the proportional distance of neutral plane from tension side of beam.
d_r = real distance of neutral plane at rupture from tension side of beam, inches.
d_e = real distance of neutral plane at rupture from that fiber on compression side which has just reached the elastic limit, in inches = Oe.
T = stress in extreme tension fiber (pounds).
T_a = sum of forces on tension side = area OLT (pounds).
C_a = sum of forces on compression side = area OUCl (pounds).
d_t = distance of center of gravity of tension area from neutral plane (inches).
d_c = distance of center of gravity of compression area from neutral plane (inches).
M_r = sum of the internal moments about the point O, in inch-pounds.

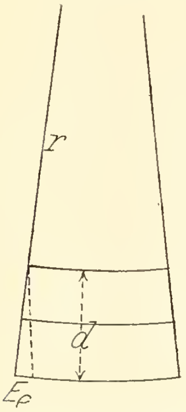


Diagram 10. — Fiber distortion in unit length of beam, at elastic limit.

The formulæ connecting these quantities are derived as follows:

To find E_e let diagram 10 represent a portion of the beam one unit in length bent to its elastic limit; then,

$$\frac{E_e}{1}=\frac{d}{r},$$

where r is the radius of curvature, but from fundamental formulæ true at elastic limit

$$\frac{1}{r}=\frac{m}{\mathrm{EI}}=\frac{\mathrm{P}l}{4\mathrm{ET}}=\frac{12\varDelta_e}{l^2}\therefore(1)\ E_e=\frac{12\varDelta_e d}{l^2}.$$

Since this involves only geometric relations. it is true also at rupture (since the beam preserves its original form).

$$(2)\ E_r=\frac{12\varDelta_r d}{l^2}.$$

To find d_p and T:

Since the sum of stresses on the tension side = sum of stresses on compression side,

$$\text{the area OLT}=\text{area OUC}l\therefore\frac{d_p}{2}\mathrm{T}=(E_r-d_p)\mathrm{C}-\frac{E_e\mathrm{C}}{4}\ \text{and}\ \mathrm{T}=\frac{d_p\mathrm{C}}{\frac{1}{2}E_e}$$

(from the similar triangle OLT and Oel (diagram 9)

$$\therefore\frac{d_p^2\mathrm{C}}{E_e}=(E_r-d_p)\mathrm{C}-\frac{E_e}{4}\mathrm{C}$$

whence,

$$(3)\ d_p=\sqrt{E_r\times E_e}-\frac{E_e}{2},$$

and after d_p is found, T can be obtained:

$$(4)\ \mathrm{T}=\frac{d_p\mathrm{C}}{\frac{1}{2}E_e}$$

Now when the vertical line LU is assumed to represent the real depth of beam in inches = d, every vertical measure will be changed in the ratio $\frac{d}{E_r}$ (see Diagram 11) — whence:

$$(5)\ d_r=\frac{d}{E_r}d_p$$

(real distance of neutral plane from tension side).

$$(6)\ d_e=\frac{1}{2}\frac{d}{E_r}E_e$$

($\frac{1}{2}$ because E_e total distortion, while d_e is the distance on one side of the neutral plane).

The area OLT would then become:

$$(7)\ \mathrm{T}_a=\frac{d_r\mathrm{T}}{2},\ \text{and the area OUC}l=$$

$$(8)\ \mathrm{C}_a=(d-d_r)\mathrm{C}-\left(\frac{d_e}{2}\times\mathrm{C}\right)$$

(C_a must equal T_a).

The distance of centers of gravity would be:

$$(9)\ d_t=\tfrac{2}{3}d_r$$

$$(10)\ d_c=\frac{d-d_r}{2}+\frac{d_e}{4}$$

and the sum of internal moments,

$$(11)\ M_r=(\mathrm{C}_a d_c+\mathrm{T}_a d_t)b,\ \text{and since}\ \mathrm{C}_a=\mathrm{T}_a,\ \text{hence}\ M_r=\mathrm{C}_a(d_c+d_t)b.$$

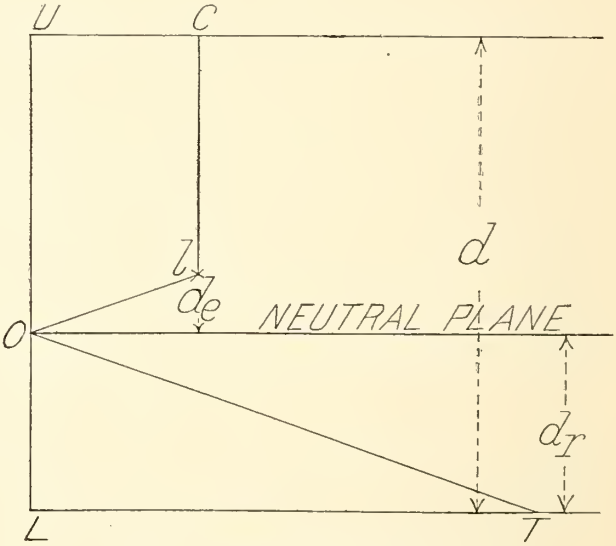


Diagram 11.—Position of neutral plane at rupture.

But since the sum of internal moments equals the sum of external moments:

$$\frac{P_r l}{4} = M_r = C_a(d_c + d_t)\, b.$$

And since P_r is the breaking load of the beam, and C_a involves only the compression endwise strength and lineal dimensions, we have a formula directly connecting the breaking load of a beam with the compression strength.*

Application of these formulæ.—Unfortunately no tests have been made to study the application of these formulæ directly and in particular. The tests on beams published in this circular were made for a different purpose. For the purpose of ascertaining the correctness of the formulæ only the tests made on large beams have been utilized, since in these the deflections were specially accurately measured. In addition to the quantities to be calculated already given in this discussion, the fiber stress at the true elastic limit is also calculated, and called S_e, to be compared with C, and the load producing it, P_e, is also set down as an observed quantity. If the modulus of rupture, R, has already been calculated by the "ordinary formula," S_e can be obtained from the relation $\frac{S_e}{R} = \frac{P_e}{P_r}$ and

(12) $S_e = \frac{P_e}{P_r} R$.

The modulus of elasticity at true elastic limit E_e is recomputed as a check, and of course is:

$$(13)\quad E_e = \frac{S_e}{\frac{1}{2} E_e}.$$

Since P_e is an arbitrary quantity within certain limits, and can not be determined with any degree of accuracy, S_e will be found to differ more or less from C. For these reasons, however, C is a more reliable value for the true elastic limit than S_e itself, and in the formulæ is used as such; for instance, E_e is the fiber distortion produced by the same load which produces a fiber stress = C, not by the load which produces S_e.

The following table exhibits the results of applying the formulæ to the data from these tests:

[*The factors $d_c + d_t$, within such limits as the crossbending strength is constant, are constants; they will have to be ascertained by actual experiment for each species and quality, and might then be expressed as a proportion of the depth. In the material used, pine as well as oak, it appears to be about 3/5. The material on which this relationship has been mainly studied was green wood, and it may be questioned whether the factors d_c and d_t would remain the same in material of all moisture conditions. There is no logic which would lead us to expect a difference greater than the limits of "maximum uniformity," i. e., 10 per cent. A few comparisons of data obtained from material of other species with varying moisture percentage indicate that a difference does not exist.—B. E. F.]

TABLE IX.—*Relation of results observed and calculated by usual methods and results calculated by Neely's formulæ.*

Kind of wood.	Original number of beam.	Data observed and calculated by usual methods.											Results calculated by Neely's formulæ.											
							Dimensions of beams.								Total fiber distortion due to bending.				Real distance of neutral plane at rupture.			Sum of forces for unit width of beam.		Distance from neutra plane of center of gravity.	
		Compression endwise strength.	Bending strength.	Load at rupture.	Modulus of elasticity.	Deflection at rupture.	Length.	Depth.	Breadth.	Load at true elastic limit.	Deflection at true elastic limit.	Actual sum of external moments about point *O* at rupture.	Sum of internal moments about point *O* at rupture.	Bending strength at true elastic limit.	At elastic limit.	At rupture.	Modulus of elasticity at true elastic limit.	Distortion in extreme tension fiber at rupture.	From tension side of beam.	From that fiber on compression side which has just reached elastic limit.	Stress at rupture of extreme tension fiber.	On tension side.	On compression side.	Of tension area.	Of compression area.
		C	R	P_r	E	Δ_r	l	d	b	P_e	Δ_e	$\frac{P_r l}{4}$	M_r	S_e	E_e	E_t	E_e	d_p	d_r	d_e	T	T_a	C_a	d_t	d_c
		Lbs. per sq. in.	Lbs. per sq. in.	Lbs.	1,000 lbs.	Inches.				Lbs.	Inch.	Inch pds. 1,000.	Inch pds. 1,000.	Lbs.	Inches.		1,000 lbs.	Inches.			Lbs. per sq. in.	Lbs.		Inches.	
Shortleaf Pine	12	*3,850*	7,360	28.000	**1,711**	3.10	192.0	11.87	7.87	13,000	1.02	**1,344**	**1,334**	*3,420*	0.0039	0.0120	**1,752**	0.0049	4.85	3.86	9,700	23,400	23,300	3.23	3.99
Do	28	*3,590*	6,670	23,500	**1,483**	6.24	216.0	11.9	8.2	13,300	1.80	**1,269**	**1,350**	*3,780*	0.0055	0.019	**1,373**	0.0075	4.70	3.44	9,810	23,053	22,760	3.13	4.03
Do	9	*4,030*	8,300	32.800	**1,630**	6.16	192.0	12.0	8.0	19,000	1.50	**1,574**	**1,541**	*4,800*	0.0059	0.0240	**1,630**	0.0089	4.45	1.47	12,200	27,100	27,400	2.97	4.14
Do	10	*3,900*	7,440	29,400	**1,340**	4.31	192.0	12.0	8.0	17,000	1.39	**1,411**	**1,392**	*4,300*	0.0054	0.0168	**1,400**	0.0068	4.86	1.93	9,800	24,000	24,000	3.24	4.05
Do	13	*4,100*	7,320	29,800	**1,540**	4.06	192.0	12.1	8.1	17,000	1.36	**1,430**	**1,460**	*4,180*	0.0053	0.0158	**1,570**	0.065	5.00	2.01	9,920	24,800	25,010	3.33	4.03
Do	29	*4,450*	7,410	24,500	**1,703**	4.86	216.0	11.75	7.9	16,000	1.92	**1,323**	**1,410**	*4,800*	0.0058	0.0150	**1,703**	0.0064	5.01	2.27	9.820	24,600	24,900	3.34	3.94
Do	33	*4,350*	7,450	26,400	**2,017**	3.36	216.0	12.06	8.0	16,000	1.48	**1,425**	**1,394**	*4,520*	0.0046	0.0104	**2,000**	0.0047	5.45	2.84	8,350	22,700	22,600	3.63	4.03
Do	38	*4,500*	7,710	27,240	**1,718**	5.57	216.0	12.0	7.95	16,000	1.77	**1,470**	**1,571**	*4,590*	0.0055	0.0172	**1,670**	0.0069	4.90	1.92	11,300	27,600	27,600	3.26	4.03
Longleaf Pine	43	*5,300*	8,850	33,550	**1,715**	4.90	216.0	12.3	8.1	20,000	1.97	**1,811**	**1,887**	*5,330*	0.0062	0.0155	**1,718**	0.0067	5.32	2.46	11,500	30,500	30,500	3.54	4.10
White Pine	51	*3,330*	5,300	18,700	**1,320**	3.75	216.0	12.1	7.95	12,000	1.69	**1,009**	**1,085**	*3,400*	0.050	0.0116	**1,340**	0.0051	5.30	2.60	6,780	18,000	18,000	3.53	4.05
Red Oak	3	*3,030*	6.570	25,800	**1.646**	7.94	192.0	12.0	8.0	9,000	1.50	**1,238**	**1,255**	*2,300*	0.0059	0.0310	**1.642**	0.0106	4.10	1.14	11,000	22,500	22,200	2.73	4.23
Do	4	*4,460*	8,640	31,500	**1,825**	5.93	216.0	12.25	8.0	20,000	1.90	**1,701**	**1.675**	*5,480*	0.0060	0.0187	**1.828**	0.0076	4.98	1.96	11,330	28,100	28,100	3.32	4.13
Do	8	*3,470*	6,870	26,000	**1,485**	6.70	216.0	12.25	8.37	14,000	1.71	**1,404**	**1,437**	*3,700*	0.0050	0.0200	**1,480**	0.0075	4.60	1.53	10,400	23,900	23,600	3.07	4.21

NOTE.—Columns of figures in same distinctive type to be compared one with the other.

In order to see how far the formulæ may be applicable to beams of the same material the data obtained on the small beams cut from one of the large beams were subjected to scrutiny, basing the calculations on the data from the adjoining compression block. The calculated result compared with the actual breaking load showed a most convincing similarity, as will be apparent from the table herewith presented:

TABLE X.—*Strength of small beams, calculated by Neely's formulæ from compression strength, on the assumption that the relative position of the neutral plane at rupture is the same as found in large beams.*

[Short-leaf Pine, large beam No. 13, special series.]

	Data observed in testing.						Results calculated by Neely's formulæ.											
	Dimensions of beams.								Real distance of neutral plane at rupture.			Sums of forces for unit width of beam.		Distance from neutral plane of center of gravity.				
Number of beam.	Length.	Depth.	Breadth.	Bending strength as calculated by ordinary formula.	Compression endwise.	Observed load at rupture.	Load at rupture, as calculated by Neely's formula, from compression strength.	Bending strength at true elastic limit.	From tension side of beam.	From that fiber on compression side which has just reached elastic limit.	Stress at rupture of extreme tension fiber.	On tension side.	On compression side.	Of tension area.	Of compression area.	Sum of internal moment about point O at rupture.	Load at true elastic limit.	Deflection at true elastic limit.
	l	d	b	R	C	P	P_r	S_e	d_r	d_e	T	T_a	C_a	d_t	d_c	M_r	P_e	Δ_e
	Inches.			Lbs. per sq. in.		Lbs.		Lbs. per sq. in.	Inches.		Lbs. per sq. in.	Lbs.	Lbs.	Inches.		Inch pounds.	Lbs.	Inch.
2	50	3.51	3.56	7,350	4,430	**4,300**	**4,708**	3,760	1.46	1.23	10,517	7,677	7,719	0.97	1.18	58,760	2,200	0.296
3	50	3.75	3.37	7,910	4,610	**5,000**	**5,310**	4,430	1.56	1.31	10,979	8,564	8,552	1.04	1.26	66,380	2,800	0.391
4	50	3.55	3.60	7,790	4,560	**4,710**	**5,057**	3,969	1.48	1.24	10,885	8,055	8,026	0.99	1.19	63,216	2,400	0.413
5	50	3.49	3.50	8,230	4,070	**4,680**	**4,203**	4,220	1.45	1.22	9,675	7,014	7,061	0.97	1.17	52,535	2,400	0.345
6	50	3.58	3.54	7,750	4,150	**4,690**	**4,571**	4,296	1.49	1.25	9,894	7,371	7,376	0.99	1.20	57,144	2,600	0.356
7	59	3.53	3.50	7,810	4,160	**4,540**	**4,420**	4,129	1.47	1.23	9,943	7,308	7,290	0.98	1.18	55,248	2,400	0.431
8	50	3.56	3.54	7,470	3,870	**4,470**	**4,578**	4,178	1.48	1.25	9,164	7,381	6,840	0.99	1.20	57,222	2,500	0.440
[a] 9	50	3.52	3.54	5,130	3,880	**3,000**	**4,169**	3,078	1.47	1.23	9,274	6,816	6,751	0.98	1.18	52,118	1,800	0.328
10	50	3.52	3.45	7,510	3,680	**4,280**	**3,854**	3,860	1.47	1.23	8,796	6,465	6,403	0.98	1.18	48,177	2,200	0.387
11	50	3.47	3.52	6,370	3,750	**3,600**	**3,312**	3,893	1.44	1.21	8,926	6,427	6,485	0.96	0.87	41,400	2,200	0.372
12	50	3.48	3.54	6,580	3,540	**3,760**	**3,697**	3,395	1.45	1.22	8,415	6,101	6,124	0.97	1.17	46,219	1,940	0.300

[a] Failed, due to knot.

NOTE.—Columns of figures in same distinctive type to be compared one with the other.

It is hoped that the very important results of the timber physics work of the division, set forth in this circular, will be a sufficient warrant for the continuance of this line of work. Not only should the general scientific investigations into the character and behavior of wood be carried forward with all vigor, but standards of strength and knowledge of other technical properties of our wood supplies should be established without delay.

The subject is thoroughly germane to the Division of Forestry from the technical point of view, since it concerns itself with the nature of the crop which the forester is to grow; and also from the economic point of view, since the waning of forest supplies was primarily the reason for the existence of the Division of Forestry. Hence any information, which, like that obtained by these investigations, will surely lead to a more economical and circumspect use of these supplies, must be considered as properly falling within the domain of forestry work.

Respectfully submitted.

B. E. FERNOW, *Chief*.

Approved:
JAMES WILSON,
Secretary.

WASHINGTON, *January 2, 1898*.

(PUBLICATIONS OF THE DIVISION OF FORESTRY.)

The publications of the Division of Forestry so far issued as a result of the timber physics work are:

Bulletin 6. Timber Physics, Part I, a preliminary statement of the scope and history of timber physics and of the methods pursued in these investigations. 4°, 57 pp. Price 10 cents.

Bulletin 8. Timber Physics, Part II, being an exhaustive report of the results with Longleaf Pine. 4°, 92 pp. This bulletin is out of print.

Bulletin 10. Timber, being a brief discussion of the characteristics and properties of wood in general, with a key and list to the commercial woods of the United States. 1895. 8°, 88 pp. Price 10 cents.

Bulletin 12. Economical Designing of Timber Trestle Bridges, being an application of some of the results to practical problems. 8°, 57 pp. This bulletin is out of print.

Circulars 8 and 9 announcing results of the tests on bled and unbled Longleaf Pine.

Circular 12. Southern Pines, Mechanical and Physical Properties, giving a résumé of the results of 20,000 tests and of an exhaustive physical examination of the four species under consideration. 4°, 12 pp.

Circular 15. Summary of Mechanical Tests on Thirty-two Species of American Woods. 4°, 12 pp.

Other publications still on hand for gratuitous distribution or obtainable by purchase are:

Annual Report for 1891, containing chapters on poisoning of street trees, bamboo a substitute for wood, and discussion of Southern lumber pines.

Annual Report for 1892, 8°, 65 pp., containing statement regarding forest conditions and the forestry movement in the United States, and a chapter on the Naval Store Industry.

Annual Report for 1893, 8°, 60 pp., containing statement regarding consumption and supply of forest products and an account of German forestry methods.

Extract from Yearbook, 1894: Forestry for Farmers. 8°, 39 pp.

Extract from Yearbook, 1895: Relation of Forest to Farms, and Treeplanting in the Western Plains. 8°, 27 pp.

Bulletin 11. Some Foreign Trees for the Southern States. 8°, 32 pp.

Bulletin 13. The Timber Pines of the Southern United States. A fully illustrated monograph. 4°, 160 pp. Price 35 cents.

Bulletin 15. Forest Growth and Sheep Grazing in the Cascade Mountains of Oregon. 8°, 54 pp.

Circular 3. Increasing the Durability of Timber, brief statement of causes and prevention of decay. 8°, 4 pp.

Circular 5. Arbor day planting in Eastern States, giving instructions how to plant single trees. 4°, 4 pp.

Circular 6. Instructions for growing Tree seedlings. 4°, 4 pp.

Circular 10. Suggestions to Lumbermen in behalf of rational forest management.

Circular 11. Facts and Figures; brief statements regarding consumption and supplies of forest resources. 8°, 8 pp.

Circular 13. Forest Fire Legislation in the United States, giving résumé or reference to the laws in existence. 8°, 8 pp.

Circular 14. Is Protection against Forest Fires practicable? 4°, 4 pp.

These Bulletins and Circulars can be had at the prices noted by application to the Superintendent of Documents, Union Building, Washington, D. C., payment to be made by coin or postal note.

Where no prices are noted, a limited number of copies for free distribution is still on hand.